SPACEBORNE MICROWAVE REMOTE SENSING MISSIONS PLANNING IN TAIWAN FOR DISASTERS MANAGEMENT

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ABSTRACT**:** With the Eurasia supercontinent at her west and the Pacific Ocean at east, Taiwan is in one of the most prevalent monsoon areas. Monsoons or typhoons bring along heavy precipitation that produce great threat of mud slide and land slide in the mountains. Remote sensing satellites have been developed into a powerful environment monitoring tool for the countries with space access capability. Potential disasters occurring in remote mountain areas can only rely on satellite monitoring to provide in-time early warning information before, during, and after heavy rain. Microwave remote sensing satellite, with its advantages of all-weather and night-vision capabilities and wide swath, can provide not only in-time footprint coverage at the desired disaster locations such as barrier lakes (堰塞湖), oil spill, wildfires, etc., but also general environment monitoring and disasters assessment, general resources survey and management support. In addition to the commercial data/information providers like the Astrium GEO Information Services and the MDA RADARSAT data provider, the data right issue and data availability prioritization to the users in other countries of the world remains to be an existing practice of the national satellite data/information providers, especially for sensitive data. Therefore, two microwave satellite remote sensing missions (via spaceborne active Synthetic Aperture Radar (SAR) and passive MicroWave Radiometer (MWR) remote sensing techniques) have been planned by the National SPace Organization (NSPO) mission development teams in Taiwan. The two missions have been independently planned by selecting its own mission orbit and mission system architecture for maximizing the data/information acquisition for the disasters locations (such as those SAR data for assets, risk, hazard, reference, and rapid mappings) or the rainfall information via MWR remote sensing for monitoring of the incoming typhoons and monsoons (out of the ranging distances of radars in the Taiwan island) with the capability of providing early warning information for the disasters management community.

KEYWORDS: Microwave Remote Sensing, Satellite Mission, Disasters Early Warning

1. INTRODUCTION

Spaceborne microwave remote sensing techniques have been employed in many developed countries after World War II. In Taiwan, these techniques have been studied ever since the establishment of NSPO. However, no such mission planning effort has been initiated until 2008. NSPO of Taiwan has been instumental in developing various space missions and programs since 1992.

2009 Typhoon Morakot has awakened the disasters management community in Taiwan to act proactively to face the possible future mega disasters. NSPO has been contributing to the community in supplying optical remote sensing data/information via the FORMOSAT-2 satellite which was developed and has been operated by NSPO. However, the optical satellite remote sensing of the landmass surfaces will be limited (even totally blocked) by the cloud system during typhoons and monsoons. Before the occurrence of the 2009 Typhoon Morakot disaster, NSPO, National Science and Technology Center for Disaster Reduction (NCDR), National Center for Research on Earthquake Engineering (NCREE), Central Weather Bureau (CWB) of Taiwan had three meetings at NCDR in 2008 for discussing potential meaningful future space missions for disasters management support in Taiwan in addition to the existing and planned optical remote sensing missions. Two specific spaceborne missions and their associated primary payloads for the NSPO microsatellite or the NSPO small satellite were identified and concluded in the meetings and the two missions were encouraged to be studied and developed are: 1) SAR mission, and 2) MWR mission via microwave remote sensing techniques under the constraint of employing NSPO's heritage space platform capability for a reasonable lower cost approach.

Realizing that limited resource can be allocated for the space system development, NSPO, NCU, and NCTU have defined two microwave remote sensing missions for Taiwan. The mission definition process involves all the needed iterations to derive mission requirements and/or mission objectives first and then flow them down to many system and payload design requirements under the constraints of low cost mission with the design goals like small size satellite light weight and less power hungering payload(s) suitable for the potential small satellite launcher(s). It is also important to satisfy the vital interests for the possible mission operations requirements from the disasters management community in Taiwan. The satellite payloads defined and their design has been performed in parallel with the mission definition process since the payload design normally will make significant impacts to the mission requirements as well as the needed mission system architecture.

2. MISSIONS PLANNING

A complete set of user requirements was surveyed in Taiwan by gathering information in the domestic user conferences for both the SAR and MWR missions. With the spaceborne applications requirements also investigated and documented to better understand the user requirements surveyed, an iterative derivation process was performed by the NCU and NSPO SAR team (Chen, K.S., et al) to form a set of SAR mission and payload requirements. Similarly, the MWR mission has been defined with a MWR payload under design by NCTU for satisfying the payload requirements from the NCU science team (Liu, G.R., et al). These missions have been further planned with a mission system architecture as follows.

The mission system architecture shall at least comprise of the following elements: 1) Mission Operations, 2) Orbit, and 3) a Communications Architecture. The communications architecture can be constructed with the following two mission system segments.

1) Space Segment:

It consists of a Spacecraft (i.e., a Small Satellite bus herein), a Primary Payload such as the SAR Instrument or the MWR Instrument) for data acquisition, and other possible payload(s). The spacecraft shall provide the necessary on-board data handling capability for data compression if needed under the existing NSPO data downlink capability via X-band in addition to the existing S-band TT&C capability.

2) Ground Segment:

The key elements for the communications architecture within the existing ground segment of NSPO are: TT&C stations are of S-band, and Receiving Only Stations in Taiwan are of X-band in Taiwan. Foreign Receiving Only stations may be considered as needed.

2.1 SAR mission

The SAR mission definition and requirements derivation process involves iterations with mission feasibility check and space system hardware availability check because the SAR satellite is an integrated system (i.e., SAR payload and its satellite bus cannot be designed separately). The SAR mission definition document (MDD) has been written by the mission team of NCU, NSPO, and NCTU (Chen, K.S., et al) and published in the APSAR2011 conference (Yaung, J.Y., et al).

2.1.1 SAR mission definition process

Since the SAR mission is to satisfy the user requirements as much as possible especially for the users who are supporting the disasters management in Taiwan, the first primary mission objective has focused on supporting disasters management by providing needed information especially on early warning**.** With this mission objective in mind, the SAR team has established the preliminary SAR mission requirements via a process involved with iterations. The process used for the SAR mission requirements derivation is illustrated with the following steps:

1) Investigate the established user requirements for each feasible application category for establishing a feasible mission system architecture including Mission Operations, the selected mission orbit, space, and ground segments

2) Make a list of mission objectives

3) Decide the image quality requirements for the targets of interest (with their priorities)

4) Check the mission feasibility with the mission system parameters derived under the small satellite launcher constraints

5) Check the link connectivity with the payload parameters defined with feasible payload technologies especially the parameters of antenna and High Power Amplifier (HPA) subsystems

6) Exercise mission operations scenarios to verify that the key mission objective(s) can be satisfied

7) Review the steps from step 2 up to this step for technical consistency

8) Repeat the process from whichever point of uncertainty to make the derivation more concrete

9) Conclude this process with a set of mission requirements (preliminary ones first, then the established ones for the Mission Requirements Document (MRD) to be written for the future program)

A list of mission objectives used for the SAR mission definition is shown below.

- To support the disaster management services and/or operations in Taiwan (especially for disasters early warning) and to satisfy other potential user requirements
- To perform the environmental watch and monitoring over the oceans neighboring the Taiwan island
- To achieve finer resolution image products as needed
- To perform international cooperation activities

Two main observations modes of the SAR satellite have been derived in the process and they are shown as follows:

1) Stripmap mode

The Stripmap mode will be employed mainly for supporting disaster management services and/or operations especially over the landmass targets of Taiwan.

2) ScanSAR mode

The ScanSAR mode will be employed mainly for performing oceans monitoring near the Taiwan island.

2.1.2 SAR mission requirements derivation

The SAR mission requirements under derivation have not reached the level for the SAR MRD documentation because the necessary iteration and the requirements verification process are still required in the above mentioned process. However, a set of preliminary mission requirements derived under the process can be summarized as follows:

- Satisfying Mission Operations requirements from the information user organization(s) who is/are willing to be the sponsor(s) and/or the promoter(s) of the future space program with NSPO
- Wavelength: C-Band or X-Band
- Orbit height: near 561 km (SSO (Sun Synchronous Orbit))
- SAR observation modes: Stripmap and ScanSAR
- Incident angle: 32°~50°
- Radiometric performance: NESZ < -20 dB
- Resolution (rg & az): 5 m (Stripmap mode), 30 m (ScanSAR mode)
- Swath: 50 km (Stripmap mode) and ~ 300 km (ScanSAR mode)
- Capable of imaging both landmass and ocean targets or scenes (mainly for supporting disasters management)
- Revisit time over Taiwan: 2 per day
- Space platform: NSPO small satellite
- Launcher: small satellite launcher
- Store-and-dump capability available to reduce downlink data rate and to increase coverage for meeting the key mission objective(s)
- X-band downlink, S-band command and telemetry
- Mission lifetime: at least 5 years

2.1.3 SAR mission analysis

SAR mission system architecture has been constructed by flying the satellite within a sun-synchronous low earth orbit and the ground segment will be mainly located in Taiwan using the existing NSPO infrastructure. The orbit was selected for imaging Taiwan landmass and its neighboring oceans twice per day for satisfying the key mission objectives by providing the early warning information of disasters such as quick delivery of flood mapping information including barrier lakes (堰塞湖) mapping in the mountains.

During the establishment of the mission requirements, mission analysis has been performed based on a top-down approach (see Figure 1 for the mission analysis flow diagram used). The mission requirements (preliminary ones first) will be served as the final check to see whether the mission under definition and analysis can be documented or should be updated. Two other possible loops in the figure involve with the SAR image quality check and the launcher constraints (mainly size and weight) check.

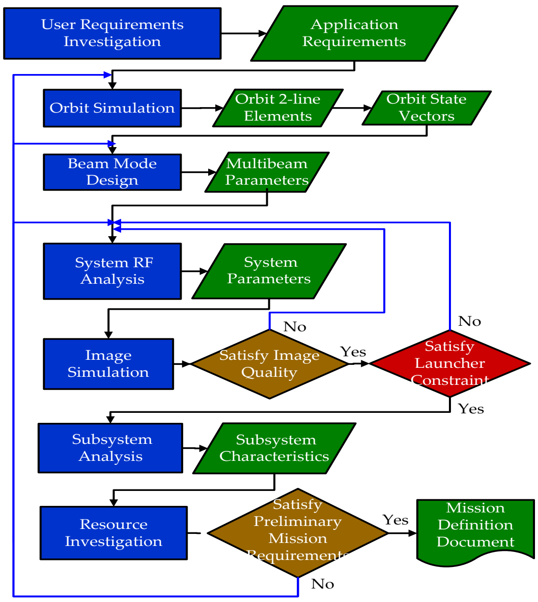

Figure 1 SAR Mission Analysis Flow Diagram

For determining the mission system parameters of the space-borne SAR mission, (i.e., parameters like spatial resolutions, polarization, frequency band and the required bandwidth, observation modes, orbit parameters, and imaging repeat cycle), one will have to iterate these parameters based on the user-driven application requirements (starting from landmass targets via the stripmap mode) based on their key image quality requirements for each mode of observation. The methodology implemented includes the orbit and mission operations simulations performed and a mission feasibility model built and the Range-Doppler algorithm used. The methodology was developed by the NCU SAR team and later documented in the reference (Yaung, J.Y., et al) and published in the APSAR conference.

2.1.4 SAR payload definition and design

The preliminary results of payload system and subsystems parameters thus derived in 2.1.3 can be used for an early characterization and understanding of the payload. This capability has been developed by the NCU SAR team led by Professor Kun-Shan Chen. Currently, two academic teams, the NCU payload definition and design team and the NCTU antenna design team, are engaged in the payload development work. The NCTU antenna design effort led by Professor Shyh-Jong Chung has contributed to the SAR mission and payload design by performing the conceptual antenna design in both reflector antenna and arrayed antenna technologies. Under the current payload system requirements defined by the NCU SAR team, these antenna design results have made significant impact to the payload system architecture design. The reflector antenna technology has been selected as the baseline technology for our current antenna design approach. Also, the antenna size has been purposely limited for easier fabrication in Taiwan and testing later. Therefore, the baseline design of X-band antenna is a multi-beam multi-feed reflector antenna with roughly 3-m diameter provided the availability of its next stage HPA subsystem can be demonstrated. A C-band system will have to be designed as well for comparison and further trade-off.

2.1.5 SAR mission operations study for disasters early warning

A SAR mission operations concept has been constructed in the SAR MDD (Chen, K.S., et al) mainly for the targets over the landmass and neighboring oceans (Taiwan Strait, Pacific Ocean, etc.) surfaces in the region near Taiwan. Figure 2 shows the coverage features of the SAR mission orbit. The orbit facilitates the daily two revisits of the satellite for its ascending and descending modes along the mission orbit within two fixed time periods when the antenna multiple beams forms the swaths with six incidence angles covering from 32 to 50 degrees.

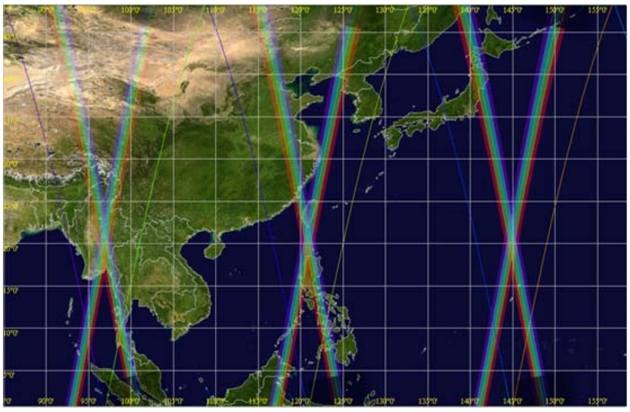

Figure 2 Coverage Features of Mission Orbit (Daily revisit, under multiple beaming conditions)

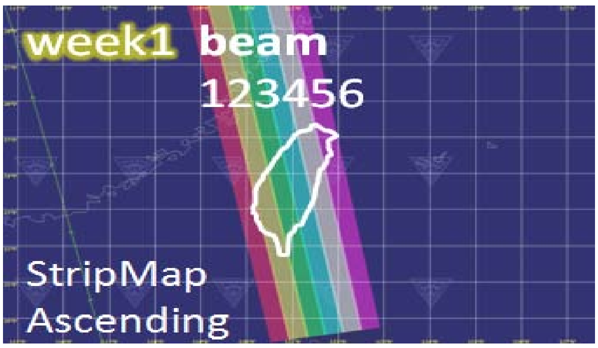

Figure 3 (a) Illustration of the Multiple Beaming Coverage

(Right beaming down and looking individually from the satellite which is ascending along the orbit)

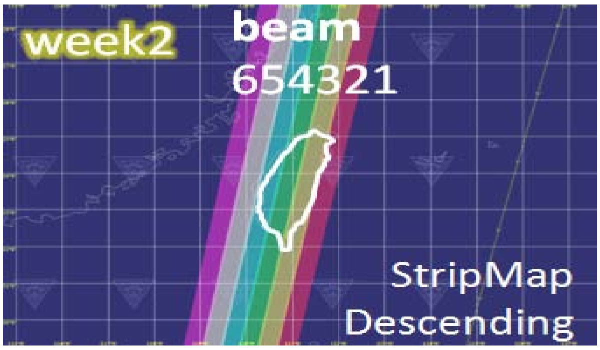

Figure 3 (b) Illustration of the Multiple Beaming Coverage

(Right beaming down and looking individually from the satellite which is descending along the orbit)

As shown in Figures 3(a) and 3(b), six antenna beams (each may form a swath of ~ 50 km) are used as the baseline design for the 3-m X-band reflector antenna design being performed by NCTU. While designing the needed beam widths, NCTU has also been required to design a high gain (~ 42 dB) antenna pattern for reducing the requirements of employing expensive high gain TWTA technology in the HPA subsystem. These payload subsystem requirements under derivation have been closely examined by NSPO and NCU with TWT/TWTA technology data sheet form the vendors/providers. Further contacts with these HPA vendors/providers will be initiated soon.

Under the feasible antenna and HPA architecture(s), one can thus explore the various possibility of power management for the payload power consumption for the different mission scenarios especially for the disasters early warning. For instances, one can exercise operations scenarios to figure out the optimal number of beams required for the beaming of the landmass areas for flood mapping including barrier lakes mapping, detection and monitoring of oil spill and wildfire under a reasonable satellite power constraint. The existing NSPO small satellite power capability should not be a constraint for these mission operations exercises due to their importance of providing early-warning information with high mission value.

2.2 MWR mission

MWR mission system architecture has been constructed by flying a satellite in a 600-km low earth orbit with a low inclination angle and the ground segment will be mainly located in Taiwan using the existing NSPO infrastructure. The orbit height has been selected for determining the required parameters for the MWR payload development in Taiwan. A MWR mission definition document has been written by the mission and payload team of NCU, NCTU and NSPO (Liu, G.R., et al) and its first version shall be releasable by the end of this year. A tentative mission operations concept has also been derived based on the important mission objective of monitoring typhoons in the Pacific Ocean for providing the needed early warning rainfall information by detecting the incoming typhoons and tracking them before their arrivals of the countries like Philippines, Taiwan, and Japan.

2.2.1 MWR mission definition process

The process used for the mission definition is illustrated with the following steps:

1) Understand the user groups needs for each feasible application category for establishing a feasible mission system architecture including the Mission Operations, the selected mission orbit, space, and ground segments

2) Make a list of mission objectives

3) Decide the image quality requirements for each payload frequency for the targets of interest

4) Check the mission feasibility with the mission system architecture derived under the constraints of a feasible small satellite launcher for measuring the targets of interest with a defined MWR payload

5) Review the steps from step 2 up to this step for technical consistency

6) Repeat the work from whichever point of uncertainty to make the process more concrete

7) Conclude this process with a set of needed mission system and payload parameters for the mission defnition

2.2.1.1 MWR mission objectives

A list of primary mission objectives used for the MWR mission definition is shown below.

- To detect and monitor heavy rainfall weather systems and provide precipitation information to the needed countries as early as possible
- To improve the accuracy of rainfall estimation and better understand the rainfall physical processes in the tropical and subtropical regions
- To share the relevant MWR data, techniques, and research results with other international satellite agencies/academic organizations, and to play an important role in the regional/global monitoring networks for disastrous weather systems

The secondary mission objectives for each primary mission objective mentioned above have also been documented in the MWR mission definition document (Liu, G.R., et al).

2.2.2 MWR payload under definition

To achieve the above mentioned mission objectives, the team used an approach by developing a wide swath (near 1,200 km) MWR payload in Taiwan to fly over the tropical and subtropical regions similar to the USA/Japan TRMM mission by increase the revisit frequencies for satellite remote sensing over the regions with better understanding of the genesis and evolution of the typhoons in the North Western Pacific Ocean area first.

2.2.2.1 Payload requirements and conceptual design performed

The MWR payload is to be operated at the orbit height of 600-km altitude with a low inclination angle (near 30 degrees or less), the design requirements for the channels of six desired frequencies have been determined as shown in Table 1 by the NCU science team led by Professor Gin-Rong Liu.

Table 1 Key MWR Payload Requirements

Parameters	Value(s)
Channel Center Frequency (GHz)	6.9, 10.7, 18.7, 23.8, 36.5, 89
Orbital Altitude (km)	600
Resolution (km)	64, 42, 23.7, 18.6, 12.3, 5
Swath (km)	near 1,200
Polarization	Dual (except the 23.8 GHz channel)
NEΔT (K)	0.4, 0.6, 0.7, 0.7, 0.5, 0.9

With the NEΔT requirements defined in Table 1 for the frequency channels as the sensitivity requirements for the instrument which are coupled with the spatial resolution requirements also in Table 1, a conically scanned reflector antenna (near 1-m diameter) has been selected and designed with the other payload subsystems by the NCTU engineering team led by Professor Shyh-Jong Chung. Knowing that the spatial resolution requirements of the 6.9 GHz channels will be difficult to be satisfied, the team has thus limited the antenna size to be near 1 meter for its easier fabrication in Taiwan and higher possibility to be accommodated in space platform.

2.2.2.1.1 Hardware verifications

In order to verify the design performed for the establishment of the MWR payload requirements, the NCTU engineering team has fabricated a prototype conically scanned antenna and a prototype one-channel (23.7 GHz) receiver system. Their functions and performances are to be measured individually in the summer of this year for the verifications or adjustment of the payload requirements.

2.2.3 MWR mission operations study for disasters early warning

The MWR Payload has been designed for operations mainly over the tropical and subtropical regions (i.e., within the lower latitudes of the Earth). In the MWR MDD (Liu, G.R., et al), we have defined the following Pacific Typhoons Monitoring Region (PTMR) for the investigation of optimal orbit parameters. It is a region tentatively defined to be bounded by the following four corner points (i.e., intersections of the latitude lines specified below with the longitude lines specified below) in the Earth map:

(1) Intersection of the 35-degree line in North Latitude and the 120-degree line in East Longitude,
(2) Intersection of the 35-degree line in North Latitude and the 180-degree line in East Longitude,
(3) Intersection of the Equator line and the 120-degree line in East Longitude, and
(4) Intersection of the Equator line and the 180-degree line in East Longitude.

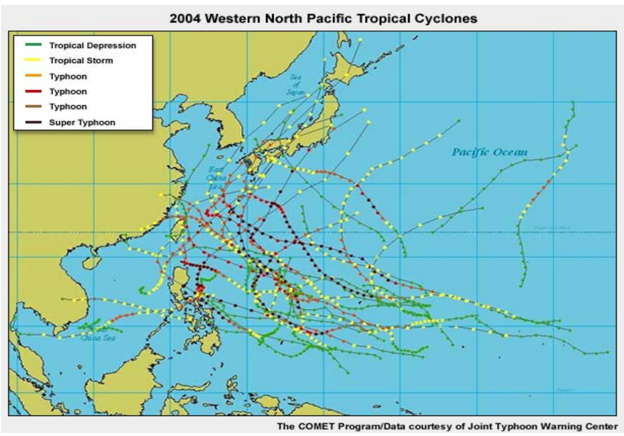

Figure 4 2004 Western North Pacific Tropical Cyclones (used for illustration of typical typhoons tracks in the PTMR)

From Figure 4, one can envision that the coverage provided by the 1,200-km footprint MWR payload remote sensing in a 30-degree inclined orbit should be able to provide the typhoons monitoring functions by providing in-time rainfall information for Philippines, Taiwan, and Japan. Many simulations using the STK mission analysis software have been performed in NSPO for studying the revisit frequencies of the satellite MWR payload. Preliminary results have shown that calculated daily revisit frequencies of detection points within the PTMR can vary from 1.5 to 4.2 (in average) for the targets to be remotely sensed by the MWR payload. We are still in the process searching for the optimal orbit with an inclination angle which will have more uniform (and high value of) daily revisit frequencies (in average) in the PTMR.

3. CONCLUSION

As one can see from the above discussions and presentations of the status, findings, results, and action plans of the spaceborne microwave remote sensing missions planning in Taiwan, the process can take years to accomplish a complete work before their space program(s) to be initiated. Thanks to the platform of this SSMS 2012 conference with its emphasis on disasters management, the NSPO microwave remote sensing missions planning team has focused more on the key mission scenarios for providing information to the organizations on disasters early warning due to its higher mission value. In order to make these two microwave remote sensing missions to be recognized in Taiwan, presentations of the findings/results of the team colleagues have been encouraged to promote the inter-agency interactions and communications within the government of Taiwan in the professional level.

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